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52 MHZ RF SYSTEMS FOR PETRA II AND HERA PROTON SYNCHROTRONS

L.W. FUNK, J.C. BROWN, R.J. BURTON, S.T. CRAIG, M.S. DE JONG, R.M. HUTCHEON, P.J.P. BUNGE, A.B. HOOD, A.G. CRACKNELL, T. TRAN NGOC
Chalk River Nuclear Laboratories, Chalk River, Ontario, CANADA

Abstract 52 MHz rf systems, including cavities, higher order mode dampers, amplifiers, feedback systems, resonance controllers, tuners and computer control systems are being provided by CRNL for the PETRA II and HERA proton synchrotrons, at DESY, in Hamburg, West Germany. The PETRA II systems have been installed in the ring and accepted by DESY. The 52 MHz HERA systems are undergoing pre-acceptance tests at CRNL and will shortly be shipped to DESY, for installation at the conclusion of the current test run of the electron machines. We review the specifications for the two systems, describe what was achieved, and report on commissioning and operating experiences.

INTRODUCTION

The requirements and specifications of these rf systems have been previously described[1,2] and are briefly summarized in Table I. Since the previous report, the PETRA II systems have been installed in the PETRA tunnel, commissioned and tested with electron beams. The HERA 52 MHz rf systems have been built, and initial high power testing has begun.

OPERATING EXPERIENCE - PETRA II

The systems were installed, commissioned and tested at DESY, initially in the hall immediately adjacent to their designated ring location. All specifications of the system were met, except for a persistent problem of sparking across the gap ceramic in one of the cavities, and an excess of mains noise in the band 200-400 Hz from the fundamental. Several attempts were made to eliminate the sparking, assuming that it occurred through charging of the ceramic, with the supporting bellows assembly acting as an electron source when heated by rf currents.

TABLE I 52 MHZ SYSTEMS SPECIFICATIONS

	PETRA II	HERA 52	
Rf frequency	51.63-52.03	52.03-52.05	MHz
Total Circumferential			
Voltage - Capture	50	30	kV
- Acceleration	50	60-100	kV
- Compression	190	290	kV
Harmonic Number	400	1100	
Average Beam Current	0.17	0.17	A
Number of Cavities	2	2	
Voltage Stability	±2%, ±5°	±2%, ±5°	
Open Loop Feedback Gain	≥50	≥50	
Feedforward Compensation	available	≥90%	

Sparking caused by tracking or simple thermal effects was ruled out by the essentially random spatial distribution of visible sparks, and the time distribution of second and third sparks. The "cures" always worked for a short time, but sparking would recur after extended operation. Finally the ceramic in this cavity was replaced with one known to have significantly lower dielectric loss tangent. No further sparking problems have been observed. No satisfactory explanation of the connection between loss tangent and sparking has been developed.

Mains noise was eliminated by re-routing of some cables.

The layout of the PETRA II ring, which must accelerate electrons and positrons as well as protons, includes a by-pass line, so that the protons are shielded from the electron cavity impedance. The small proton cavity impedance is not expected to affect the electron beam, so the e-beam will traverse the 52 MHz cavities. The cavities were installed in the ring in October 1988, and very shortly thereafter were exposed to electron beams. Special instrumentation was installed to observe wake fields excited in the cavities by the short electron bunches. Both single- and multi-bunch runs were made, at equivalent current levels higher than those expected when filling HERA for luminosity runs. As expected, many higher order modes were excited, but no feedback to the beam could be observed. Heating of gap ceramic and bellows was observed, but at a much lower level than that experienced during normal operation at 52 MHz. First operation with protons is anticipated in October or November of this year.

The early decision to rely on computer-mediated interlocks for component protection put a premium on computer reliability and soft-ware quality. These were achieved with standard industrial computer systems and high level languages, so that this approach has worked very well. Response time is comparable to that for relay inter-lock systems and the computer hardware/software has been the most reliable subsystem. Most important of all, the interlock configuration could be quickly and reversibly modified as needed during system integration, so that operation of a partial system was possible with maximum safety. This greatly smoothed integration and commissioning.

Communication with DESY is via their custom SErial Data ACquisition system, SEDAC. Special hardware and software had to be developed for the interface. Initial difficulties in defining and implementing suitable protocols have been overcome, and DESY is writing the supervisory software for their control computers.

The most demanding amplifier specification is the ability to cope with transient beam loading. The high average current, and the fact that the proton bunches cross the accelerating gap at, or near, the zero in the gap voltage, means that large amounts of compensating power are delivered into the final amplifier plate. Since test beams were not available, it was decided to try to simulate this situation by frequency modulating the cavity drive at the beam revolution frequency, with a deviation which resulted in the same rate of change of phase as that expected from the beam. The amplifiers were able to handle this dissipation at all specified gap voltages, with an adequate safety margin.

OPERATING EXPERIENCE - HERA 52

The system is undergoing pre-acceptance testing at CRNL. Witnessed acceptance testing is planned for September. Installation, commissioning and acceptance testing at DESY is to take place in October.

HERA 52 cavities differ from those of PETRA in that the former are fully evacuated. Vacuum envelope assembly and bakeout has been completed. System base pressure is expected to be $<10^{-9}$ mbar with a

400 ℓ/s ion pump after extended rf operation completes the cleanup process. Cavity Qs were about 14,000 unloaded and about 7000 loaded.

The change in cavity aspect ratio from the PETRA II design shifted the first higher order mode frequency from 125 MHz to about 145 MHz. The configuration of the HOM damper coupling loop and resistor have been adjusted to achieve maximum coupling at the new frequency. This is still comfortably distant from three times the fundamental, so that this type of damper is still useful.

A titanium film has been evaporated onto the inner surfaces of one cavity to suppress multipacting. If successful, the process will be applied to the second cavity. Simulation with NEWTRAJ[3] predicted the onset of multipacting at about 1 kV gap voltage, occurring mostly in the volume between the inner conductor and the inside of the intermediate cylinder. These surfaces received particular attention during the titanium coating process. The coated cavity multipacted at 500 V gap voltage. After a short period of conditioning this cavity operated without multipacting in pulsed mode. Attempts to achieve cw operation are underway.

A major concern during design of the final amplifier and drive loop assemblies was the achievement of minimum reactances, so that the resonant frequency of the circuit formed by the drive loop, tetrode and balancing capacitor could be kept above the operating frequency. With careful attention to compact design, and maintenance of a coaxial geometry, this goal was achieved. The measured resonances of these circuits in the two HERA 52 systems were at 63.5 and 62 MHz. Loop penetration is adjustable, to achieve the correct coupling to the cavity, with a ratio of gap voltage to plate rf voltage of 30. A complex design was necessary to meet the requirement that this be achieved without modification of the vacuum feedthroughs or disturbance of the water lines which run through the loop from the centre to the tube and balancing capacitor, and back out again. Success was achieved and step-up ratios of 27.5 and 29 were realized.

A folded, broadband, final amplifier input cavity incorporating a tube socket, and means to provide cooling air for the screen connection and water cooling to the filament, was designed to fit into the final amplifier enclosure. The completed cavity, loaded by the grid-cathode impedance of the tetrode, has a bandwidth in excess of 10 MHz. Final adjustment of the coupling to the desired 5 Ω impedance is achieved with a plunger with a tuning rate of 0.8 MHz/cm, and the overall cavity frequency is adjusted by movement of a ceramic load, which has a tuning rate of 1.0 MHz/cm.

The ten-channel solid state driver amplifier necessitates the use of a power combiner. This compact and efficient unit has input VSWRs of 1.6 or less, and prevents failure of any driver module from affecting any of the other modules. To minimize the effect of input mismatch, the amplifier modules have been connected to the combiner with lengths of coaxial line which are two 52 MHz wavelengths long.

Performance of the solid-state amplifier modules has been excellent. Individual modules provide (at 52 MHz) output of 300 W, gain > 20 dB, 3 dB bandwidth greater than 50 MHz, dc-to-rf efficiency $> 70\%$ at full output, input VSWR ≤ 2.5, gain linearity better than ± 0.5 dB at 1 A bias current, and suppression of the 3^{rd} harmonic by more than 20 dB relative to the fundamental. As combined into a 3 kW unit, with an input exciter module, 1:10 splitter and 10:1 power combiner, they achieve $>$ 40 dB gain, 35 MHz bandwidth, input VSWR < 1.8, and tolerance of VSWR up to 4 at the output of each module. Total delay from the exciter input to the ten driver outputs is 33 ns.

The lessons learned in the operation of the PETRA II analog and digital control systems were carefully applied, with the result that the commissioning of these HERA 52 sub-systems was completed smoothly and quickly. In the digital control system, the decision to utilize standard industrial modules for signal conditioning proved to be of particular value in saving time and money in manufacture, installation and commissioning. This philosophy had already been applied in the analog control system for PETRA II.

Figure 1 shows a Bode plot of the driver, final amplifier and cavity. The left feature is the main cavity response. The right feature is associated with the drive loop, balancing capacitor and tetrode. The central feature represents a two-path interference signal arising from excitation of the tuner resonance. Only the loop resonance is less than 34 dB below the cavity response, so that it will be simple to adjust the feedback path length to assure stability.

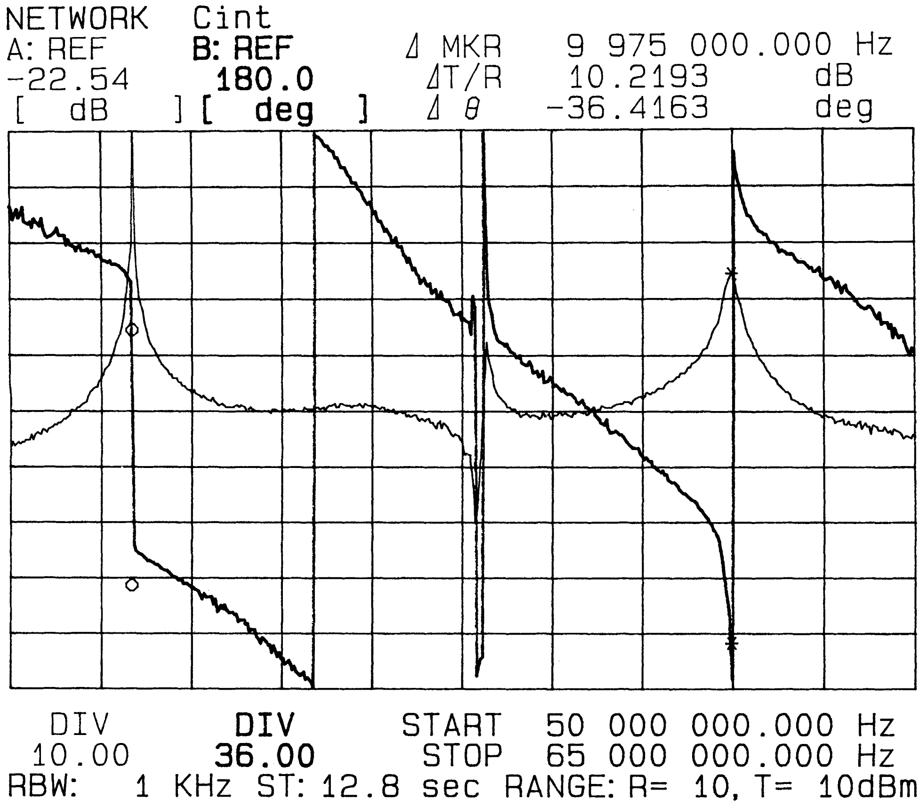

FIGURE 1. Bode plot of HERA 52 MHz system response.

ACKNOWLEDGMENTS

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